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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD ADVISORY REPORT 310

Technical Evaluation Report on the Guidance and Control Panel 53rd Symposium on Air Vehicle Mission Control and Management

(La Gestion et le Contrôle des Missions des Véhicules Aériens)

The Guidance and Control Panel's 53rd Symposium was held at the Marine Kazerne, Amsterdam, The Netherlands from 22nd—25th October 1991. All papers presented at the Symposium were compiled as Conference Proceedings 504 and 504S.

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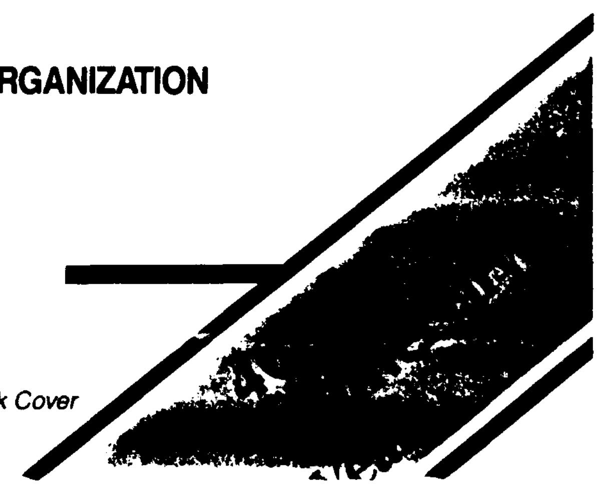

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(La Gestion et le Contrôle des Missions des Véhicules Aériens)

by

Mr Duncan E McIver
104 Montague Circle
Williamsburg, Virginia
United States

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North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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— Exchange of scientific and technical information;

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Preface

Mission control and management is becoming an increasingly important subject in vehicle guidance and control. Developments in this field provide crucial contributions to the improvement of mission effectiveness. These are related to single air vehicle missions or to multiple air vehicle missions (including air traffic), and to the whole missions or the mission elements.

The subject covers both the ground segment and the air vehicle segment of the complete system, with highly integrated concepts embracing ground-based and onboard system elements, being particularly relevant. The ground segment typically comprises a number of elements such as pre-mission tasking and planning, ground-based information sources, situation assessment and mission plan upgrading. The air vehicle segment comprises the onboard mission control and management, including situation assessment capabilities, automatic mission planning and plan execution functions. The onboard system may be used as an aid to the pilot in mission planning and tactical decision making or, in the case of an unmanned vehicle, may be fully automated.

The technical papers presented addressed the current developments and trends in air vehicle mission management, assessed the state-of-the-art and identified technological alternatives for future systems. System application issues are of primary importance. The following topics were discussed during the symposium: operational mission considerations, situation assessment, route planning, planning techniques, and implementation techniques.

Préface

La gestion et le contrôle des missions revêt de plus en plus d'importance dans le guidage et le pilotage des véhicules aériens. Les développements dans ce domaine représentent des contributions d'une importance capitale pour l'optimisation de la conduite des missions. Ils concernent des missions soit à vecteur unique, soit à vecteur multiple (y compris le trafic aérien) et ils s'appliquent soit à la totalité de la mission, soit à certains éléments de celle-ci.

Le sujet couvre le segment sol et le segment véhicule aérien du système complet, où la conception hautement intégrée des éléments du système, tant embarqués qu'au sol, est particulièrement significative. Le segment sol comprend typiquement un certain nombre d'éléments tels que l'assignation des tâches et la planification avant vol, les sources d'informations au sol, l'évaluation de la situation et la mise à jour du plan de mission. Le segment véhicule aérien comprend la gestion et le contrôle de la mission par des moyens aéroportés, y compris l'évaluation de la situation, la planification automatique de la mission et l'exécution du plan de mission. Le système aéroporté peut soit servir d'aide au pilote pour la planification de la mission et la prise de décisions tactiques, soit, dans le cas d'un véhicule non-piloté, fonctionner en mode automatique.

Les communications techniques ont examiné les réalisations et les tendances actuelles dans le domaine de la gestion des missions des véhicules aériens, présenté l'état de l'art et proposé des solutions technologiques pour la conception des systèmes futurs. Une attention toute particulière a été accordée aux questions concernant les applications. Le symposium a porté sur les sujets suivants: les missions des véhicules aériens, les techniques d'évaluation de la situation, la planification et l'exécution de la mission, et la mise en oeuvre des systèmes de gestion/contrôle des missions.

Guidance and Control Panel

Chairman: Dr E.B. Stear
Corporate Vice President
Technology Assessment
The Boeing Company
PO Box 3707
Mail Stop 13—43
Seattle, WA 98124-2207
United States

Deputy Chairman: Mr S. Leek
PB 256
British Aerospace (Dynamics) Ltd.
PO Box 19
Six Hills Way, Stevenage
Herts SG1 2DA
United Kingdom

TECHNICAL PROGRAMME COMMITTEE

Chairman:	Prof. Dr Ing. R.C. Onken	GE
Members:	IPA L. Guibert	FR
	Dr H. Winter	GE
	Dr B. Mazzetti	IT
	Ir G. Alders	NE
	Dr P. Sanz-Aranguez	SP
	Mr J. Simon Calero	SP
	Mr A.D. King	UK
	Mr J.K. Ramage	US

HOST NATION COORDINATOR

Captain (Rtd) Ir L. Sombroek
c/o National Aerospace Laboratory (NLR)
Netherlands Delegation to AGARD
P.O. Box 126
2600 AC Delft
The Netherlands

PANEL EXECUTIVE

Commandant M. Mouhamad, FAF

Mail from Europe:
AGARD—OTAN
Attn: GCP Executive
7, rue Ancelle
F-92200 Neuilly sur Seine
France

Mail from US and Canada:
AGARD—NATO
Attn: GCP Executive
Unit 21551
APO AE 09777

Tel: 33(1) 47 38 57 80
Telex: 610176 (France)
Telefax: 33(1) 47 38 57 99

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INTRODUCTION

The 53rd Symposium of the AGARD Guidance and Control (GCP) was convened in Amsterdam, the Netherlands 22–25 October 1991. The meeting was titled "Air Vehicle Mission Control and Management". The theme of the meeting was the increasingly important role that mission control and management was having in vehicle guidance and control. The meeting took on additional importance because of its impact in the recently completed war in the middle east. Further, lessons learned in that encounter provide a valuable basis for pursuing advances in mission control and management concepts and technology for the future.

Major General W. Breeschoten, of the Royal Netherlands Air Force (RNAF) gave the keynote address. He provided an excellent assessment of the importance of air vehicle mission control and management, from his experience as a fighter pilot and current assignment as Director of Operations for the RNAF. As he pointed out, the views are the same, only the scope is different.

He discussed the war in Iraq, and lessons learned which included choosing tactics appropriate for the situation and retaining flexibility. This means that aircrews and systems, including mission control support for manned airborne weapon systems, should be able to cope with all environments. The conflict also showed the importance of being able to operate around the clock. And a dominating aspect involved targetting, and the ability to hit the proper target, or probably more important, not to hit the wrong target. Finally, there was a clear message to continue efforts to standardize mission support systems for composite forces.

General Breeschoten identified the issues and challenges of mission management and control in an eloquent charge to the symposium participants:

"Being technical people, your main angle of incidence this week will be systems and enabling technology. You will address methods to harness the flow of data, and transfer it into information. You will address methods to structure the control process, so that it will be amenable to analysis, and you will exchange information on your experiences while developing systems."

"The properties of these systems and even of elements of these products are closely related to the structure of the world in which they are to be used. The opposite is also true, this user world is affected to a large extent by the possibilities of technology. Therefore, in my opinion there is an important contribution to be made by AGARD in the field of the definitions of standards, both on the technical and on the information level."

"In your work, try to contribute to the definition of adequate standardization rules, that allow the necessary variety in operations and systems, while simulating effectiveness. When considering mission control support systems, allow for versatility. Do not assume fixed scenarios. Make no optimum solutions for incomplete worlds. And last, but not least, when designing for manned systems, remember the pilot. Think about his mission and about what he really needs. Allow for use of human facilities. Keep him informed and keep him in the loop. If not, make a drone."

SESSION I: OPERATIONAL MISSION CONSIDERATIONS

The purpose of the first session was to provide real life examples of the application of mission management and control systems. As mentioned in the keynote address, the subject had become very relevant with the recently completed Middle East war and some of these experiences were addressed in the first two to five papers.

Paper 1, by W.A. Mee, from the Combat Operations Centre of the Royal Air Force (RAF), underscored the successful team aspect of winning the war. The paper described a typical mission covering all aspects from initial tasking by the ATO, through mission planning and coordination with intelligence input to deconfliction and mission execution. Mee pointed out that mission planning by the RAF was manpower intensive and could have been streamlined with the availability of more automated systems.

Paper 2 by Mr. Joe Reynes of the U.S. Air Force, described the single Air Tasking Order (ATO) used by the Joint Air Force Air Component Commander in the successful execution of the war. It was not presented at the meeting, but was expected to be included in the proceedings. As it was not received by the time of printing, it was not possible to include it in the proceedings. The paper described the ATO cycle and how the air-land battle was managed, and showed the need for real time intelligence and real time secure data transmission of the information. The paper pointed out how effectively the composite forces worked together during the war. Mr. Reynes could not be present at the symposium because of a last minute requirement to brief the Chief of Staff of the Air Force in Washington, D.C.

The third paper was by L. The, of the Netherlands, described the difficult task of mission planning for an Unmanned Air Vehicle in Naval operations.

The fourth paper, by P. Schulein, also from the Netherlands, described the use of battle management training in improving air power planning. The final presentation in this session, Paper 5, by P. Fossier of Dassault Electronique, described a modular and interactive simulator for electronic combat mission analysis and modelling.

This session gave a fascinating view of the real applications, especially the first two papers which provided important lessons from the Iraq conflict, and revealed several important directions for the future.

SESSION II: SITUATION ASSESSMENT

The purpose of this session was to establish the state or condition of the mission environment. This assessment of the situation, of course, is critical for planning the mission. The papers presented showed that you could get information on the situation and try to assess it, but the information you get is never complete.

The first presentation, Paper 6, by P. Faggion, of Alenia, illustrated procedures and techniques for automated target tracking and location for optical payloads on a remotely piloted vehicle, the Alenia Mini-RPV System. Key elements of the system to provide the information back to the remote site, are the avionics, including navigation sub-system, the

data link and the video tracker. The analysis demonstrated excellent accuracy, and potential value of such unmanned vehicles for safe and reliable battlefield observations. Paper 7, presented by M. Desbois, of Thomson-CSF, dealt with establishing the situation in a mobile multi-sensor environment.

In Paper 8, Dr. J.W. McManus, of the NASA Langley Research Center described Paladin, a real-time tactical decision generator for air combat engagements. Paladin uses specialized knowledge-based systems and other Artificial Intelligence programming techniques to address the modern combat environment and agile aircraft. Paladin is designed to provide insight into both the tactical benefits and costs of enhanced agility. The system was developed using the LISP programming language on a specialized AI workstation. Paladin uses a set of air combat rules, an active throttle controller, and a situation assessment module that have been implemented as a set of highly specialized knowledge-based systems. Paladin models aspects of the decision-making processes used by human pilots, and provides a way to evaluate knowledge-based systems in a real time environment.

In Paper 9, R.M. Taylor of the RAF Institute of Aviation Medicine, discussed the psychological principles, or human factors, for mission management systems design. His focus was on developing aircrew interfaces to aid the pilot, rather than to replace pilot functions. To address the requirements for a theory of the pilot-aiding concept, he proposed a model based on teamwork, where the pilot and the "electronic" crew work cooperatively together to achieve mission objectives.

Banavar Sridhar, from the NASA Ames Research Center, described a cooperative effort with the U.S. Army, called the Automated Nap-of-the-Earth (NOE) flight program, in Paper 10. The very ambitious goal of this program is to develop technologies for enhancing pilot performance in low altitude/NOE flight management and control, so he can devote more time to mission related activities.

This subject was complemented by Paper 11, from Alenia in Italy, which described the development of automated tools for the mission planning and control for army light aviation. The presentation also showed how the mission planning activity develops from the Army Corps level down to the the Battalion level. In describing these mission planning and control activities, particular emphasis was given to the importance of data base development.

SESSION III: ROUTE PLANNING

The purpose of this session was to describe some of the methods and techniques that are used in planning the route to the target. There were seven excellent presentations, Papers 12—18, were included in this session.

The first paper, Paper 12, was an excellent description of a knowledge-based computer aid for flight planning tasks as part of a Cockpit Assistant for IFR (Instrument Flight Rules) operation. The system is aimed at supporting the pilot in the complex planning and decision situation, required by the air traffic management. The paper described successful tests of the system in a flight simulation facility at the University of the German Armed Forces in Munich, and the possibilities of integrating the system into the avionics of modern aircraft.

Paper 13, presented by D. Hennion and J-P Balhi, from Sextant Avionique, discussed the requirements and system implementation considerations for terrain following/terrain avoidance/threat avoidance flight for combat aircraft. Mark Silbert, of the U.S. Naval Air Development Center, followed with a review of the Event-Step Algorithm (ESA), obstacle avoidance, and shows that the ESA, offers advantages over similar algorithms.

Paper 15, from Sextant Avionique and Dassault, was a description of a future onboard flight management system for combat aircraft. The flight management system mainly handles the mission itinerary, and upgrade the mission plan in the event of unexpected events. The system had been successfully evaluated in experiments on a Dassault Aviation simulator.

Paper 16, by V. Adam of the DLR, provided a valuable discussion of onboard planning of 4-D (position and time) trajectories for aircraft operating in an air traffic control system. On-board flight management systems, with this capability, working in close cooperation with the ground system have the potential for significant improvements in capacity and efficiency.

An integrated weapon delivery system, MULTACK (Multiple Target Attack System), being developed for the U.S. Air Force, was the subject of Paper 17, presented by J. Sandridge. The system enables an aircraft to attack multiple ground targets on a single maneuvering pass during day, night, and in-weather conditions. MULTACK's capability has been evaluated in by experienced aircrews in a simulator, have demonstrated significant improvements in lethality and survivability.

The final paper in this Session, was given by M. J. Hoffman, of Honeywell, and provided a unique look into the future, with a discussion of real-time trajectory optimization and guidance for hypersonic aircraft. The mission included take-off, climb-to-orbit, return-from-orbit, flight-to-designated-landing-site, unpowered abort, and powered-abort flight conditions. The study results indicate that an approximate Euler-Lagrange optimization method can be used for on-board guidance. This approach provides for high flexibility to mission changes, less operator involvement, and less launch-site support for pre-mission trajectory generation.

SESSION IV: PLANNING TECHNIQUES

This session dealt with the details of mission planning and execution, including pre-mission planning, planning in an uncertain environment, and the rationale of the planning process. Another purpose of the session was to gain some understanding of the trade-offs of optimization algorithms versus knowledge-based approaches. Papers 19—24 were presented during this session.

Paper 19, presented by E.K. Kriegel, of the Mitre Corporation, was an excellent discussion of technology and standards for a common air mission planner. Even though users are planning missions for different aircraft, they perform common functions, access identical databases, and operate with similar procedures. Kriegel described such a system being developed for The U.S. Air Force, called the Air Force Mission Support System (AFMSS) that uses an architecture based on modern computer-communications technology.

Paper 20, by J.R. Van Zandt, also of the Mitre Corporation, tackled the problem of search route planning, with the goal of minimizing the risk to the crew while maximizing the likelihood of finding targets. The aircraft need not overfly each site but just come within sensor range of it. Using a generalization of the "traveling salesman problem", he has developed a

genetic algorithm for selecting both a set of sites to visit and appropriate routing pattern.

F. Raupp, of ESG in Germany, described in Paper 21, a method for planning 3-dimensional paths for autonomous air vehicles on a terrain represented by a digital map with different strategies and constraints. Constraints considered included lateral and vertical maximum acceleration, and time and fuel limitations. The solution was a fast, non-heuristic technique for strategic route planning that used a combination of Dynamic Programming and direct optimization methods. Paper 22 was not presented.

Paper 23, presented by W. Grimm of DLR, was a description of optimal guidance methods for the pre-launch phase of missiles in air combat situations. Simulation results show a positive potential for such methods. Beside partial automation of aircraft guidance the methods could also be used in a pilot's decision aid in missile firing.

The final paper in the Session, was from INTA in Spain, and dealt with the evaluation of a fuzzy guidance system. J. R. Martin, described the results of the study, which compared the capability of a fuzzy logic controller with a classic controller. The model used for the study was the attitude control of a microsatellite launcher, during the first stage of flight. The fuzzy controller seemed to have more robustness, but additional analyses are required.

SESSION V: IMPLEMENTATION ASPECTS

The objective of the final session, was to review the currently used and planned technologies for the implementation of mission planning and control systems. For the engineers, this was a very interesting group of papers, and included Papers 26—29. Paper 25, dealing with the development of a mission planning system by the National Aerospace Laboratory in the Netherlands was withdrawn.

Paper 26, by M.R. Bowyer of the Defense Research Agency in Farnborough, discussed parallel knowledge based systems for in-flight mission management. The paper described the hardware and software architectural approach , including the modification of the Muse Real Time Intelligent Knowledge Based Systems (IKBS) toolkit to meet the requirements of in-flight mission management.

Paper 27, another paper from DLR Institute for Flight Guidance, presented by M. Schubert, described the development and operational experience with a new arrival traffic management system. The system, called COMPAS (Computer Oriented Metering Planning Advisory System), was implemented at the Frankfurt ATC Center, and has been operational since mid 1989. Results of an initial six-month field test, indicate that the planning system enabled controllers to establish preplanned optimized approach sequences and contributed to straight and easy traffic flows.

Paper 28, from McDonnell Aircraft Company, described the Integrated Control and Avionics for Air Superiority (ICAAS) system, and piloted simulator evaluations. The ICAAS program is sponsored by the U.S. Air Force, to develop technologies for improving tactical fighter performance in air combat.

The final presentation, Paper 29, was by Lee Duke of NASA Dryden, who described an Automated Flight Test Management System (ATMS). The ATMS is a tool for flight test planning and scheduling and contains expert systems for maneuver ordering, range management, and maneuver requirements evaluation. Several versions of the ATMS have been developed, and the most recent was demonstrated in mid-1990 using the F-18 High-Angle of Attack Research Vehicle (HARV).

ROUND TABLE DISCUSSION

A very important element of this symposium was the round table discussion of the presentations by a panel of experts, who also responded to questions from the audience. Riner Onken led the discussion, and assigned the following people to provide observations on each of the key areas of the symposium: James Ramage, on operational mission considerations; Ir. G. Alders, on situation assessment; E. K. Kreigel, on planning systems; Dr. Rer. Nat. H. Winter, on technology implication issues; and R. M. Taylor, on the human operator considerations.

Ramage observed that in the Persian Gulf, the Allied success could be attributed to a number of factors, the military strategy, the tactics, the availability of well motivated, highly trained people, and superior technology. The mission planning environment served as a catalyst in integrating these elements successfully. The decisiveness of the air campaign, using the single tasking order concept (described in Paper 1) involving a large multi-national force package clearly attested the effectiveness of mission planning.

He observed that some things did not work so well. Things like inter-operability involving non-NATO countries, real time adaptability to unforeseen events, and relatively inflexible tactics, were examples. And information fusion did not occur at the level that technology should have permitted. In the future, if the night and mid and low altitude is denied, and the threat environment is more severe, we may need to consider the broader use of stand-off autonomous weapons and unmanned vehicles.

Ir. G. Alders, underscored the fact that an accurate situation assessment, is critical for planning the mission. He thought that the papers in Session II showed that you could get information on the situation and try to assess it, but the information you get is never complete.

An example was the paper by Mr. Debois (Paper 7), which showed it was difficult to get the information because of jamming, etc. When you look at the air-to-ground situation, it is even more so. You know the number of threats, the number of defense systems and how they are positioned, you also know the number of assets that will be part of the enemy, but you don't know how they are planned to be employed. Therefore uncertainty plays a large part in this whole process.

Kriegel pointed out that planning takes place at a number of different levels: at the Force Management Resource Level; at Pre-Mission, in terms of flight planning and route planning; and in the on-board flight management level. Some of the algorithms are shared, for example: the threat terrain, or obstacle avoidance type algorithms; interception and end game type algorithms; and multi-target, routing and scheduling algorithms. All tended to be optimization or constraint problems, yet they are all very much dependant on the data that feeds them. Inter-operability and the automatic data feeds and the structure that these algorithms work on are critical for success in mission planning. Much of the criticism of mission planning is that the algorithms don't take the whole situation into account.

Kriegel concluded with the observation, that it is not sufficient to design the box, it is not sufficient to design the

algorithms. You have to put it in the total context of how the planner uses it, what information is available to him, how he uses it, what information is available to him, how accurate that information is. And so planning is a lot more than algorithms.

Dr. Winter, made several important observations on the technology and implementation issues discussed in the symposium presentations. He pointed out that implementation is the moment when the system has been completed and leaves the laboratory environment and comes into the real field application and meets a world full of complexity.

First, the success of the system is very much influenced by the way the operator finds his role in cooperation with the system. The situation is that a new system has comes out of the laboratory, that performs a certain function that the operator had been performing before, and now he has to share this task with a machine. This is a very complex human factors issue, and must be considered in the design stage.

Second, when you consider these systems for mission planning, you must consider the function as an additional loop to the flight control loop within the aircraft. Although these planning functions may be different for each mission, there should be some kind of standard structure for each system.

Another point Dr. Winter observed was that the technology is split into software and hardware technology, and that the software is fairly well developed and although some of the tools and supporting systems are not yet available, in the next five years we will have good standardized tools to develop the software functions. On the hardware side when you have to put systems into the airplane, there are still some bottle necks remaining

Both Onken and Winter complimented the efforts described in several papers to use artificial intelligence and knowledge-based systems technology for mission planning applications.

In introducing Taylor to talk about the human factors of mission planning, Dr. Onken reminded all of the comments made in the Key Note Address: "The key word in mission control system development is support to the user. The user must be known. System designers may think they know the user. Human factors engineers may think they know the user. The user may think that he knows himself. They are all wrong."

Taylor said he also found the General's remarks very informative. He said that it is almost a universal truth, that systems designed to aid the pilot end up increasing his workload. Mission management and control impacts on the cognitive workload of the pilot, so the cognitive quality of the mission management system should be a major design driver. The success of a mission management system however will depend on the quality of the cognitive task analysis underpinning the system design.

He commented that the papers presented during the symposium, were consistent with his views prior to the meeting, that the demands of the air borne mission are far more substantial than ground planning. And so although for ground planning what we seem to have are highly achievable objectives and the resources required to meet them. We seem to be building the kind of structures which are probably necessary. But with regard to the processes of the man-machine interface we still have major problem areas. This is more particularly so with the dynamic situation in the air, where the quality of that interface is going to be an even more determining factor.

Taylor said you should use cognitive task analysis to make explicit the assumptions that are made about the uncertainty that the operator is required to resolve, and this was a question he kept asking when he heard the presentations. What is left for the operator to do? He believed that a cognitive task analysis can provide an audit trail on the quality of that design solution.

Taylor concluded that representation of uncertainties is probably the major challenge in the design of the interface. We must be sure what we mean by plans as opposed to situated acts, because it is the situated acts that the operator in the air is being required to respond to. And what we know about that is the way in which people respond in situations is very much a recognition prime process dependant on the situation assessment, as well as providing plans. What you must be able to do is provide a situation assessment necessary to support the situated acts.

CONCLUSIONS AND RECOMMENDATIONS

This was an excellent and informative symposium, timely because of the recently completed war, and all those associated with it are to be commended. The subject matter is very important, because the issues raised for mission planning and control, have application in a broad range of areas. There is a fundamental challenge for effective conduct of missions, be they military or civilian, that requires effective planning, efficient execution, and proper accommodation for the human factor.

Looking to the future, one can see the need for more real time mission management and control with emphasis on on board interaction between the command and control centers, be they airborne or ground, the strike aircraft and their weapons, particularly with respect to autonomous unmanned type weapon, as well as the myriad of supporting ground and air elements. Underscoring all that is tactical flexibility in a multinational environment. And more emphasis should be placed on methods and systems that can cope with the uncertainty in the situation.

The interoperability of systems continues to be important, and should be a major design driver. At times during the war in Iraq, there were two systems sitting side-by-side and no way for them to communicate. There is also a need for more reconfigurable and deployable systems.

Standardization also needs to be considered. Dr. Winter made the worthwhile suggestion to consider a standard outer loop around the aircraft that does situation assessment, mission planning, decision aiding, and actuation of certain things to do. With a layout which enables you to use such a system different roles in different missions, etc. If not feasible to standardize, then there will be a number of different systems to be introduced.

With regard to implementation, there should be increased efforts to evaluate the use of artificial intelligence and knowledge based systems is relevant. The current GCP Working Group on knowledge-based guidance and control systems is a timely and important undertaking, and should give additional consideration to the issue of mission management and control.

One theme of the symposium appeared to be that mission planning is viewed as advice and guidance and it does not replace the human being. Replacing the human being may never happen, but it is essential that the human's role and involvement as a user be considered very early in the design process. Taylor posed the following important questions that should be considered:

1. What uncertainty remains for the pilot to resolve?
2. How should that uncertainty be represented to the pilot to best support his decision-making?
3. What assumptions have been made about pilot capability? (Not sufficient to just ask the test pilots)
4. Are these assumptions made explicit? Can their validity be checked?
5. Have you provided levels of autonomy necessary and sufficient for building trust between the pilot and the planning aid?

Dr. Winter was correct in his observation that the design of the man-machine interface very much depends on the functional distribution between man and machine. From discussions in the GCP Working Group on Knowledge Based Systems, which he is Chairman, the perspective seems to be that more and more this functional distribution allocation becomes dynamic in the sense that the operator can set the level of automation, or he can influence which functions he wants to be carried out by the machine or which functions he wants to carry out by himself. This creates each time a different interaction between automatic systems and human systems, so on a longer perspective the design of the man-machine interface needs to have some flexibility built into it.

APPENDIX: PROGRAMME AND LIST OF PAPERS

Paper Number

Session I: Operational Mission Considerations

1. Mee, V.A.: Interdiction Mission Planning and Co-Ordination During the Gulf Conflict 17 Jan—27 Feb 91: Royal Air Force Bruggen.
2. (Not presented) Reynes, J. et al: Air-land Battle Management in a Multinational Environment. U.S. Air Force.
3. The, L. et al: Modelling the Unmanned Air Vehicle (UAV) Flight Patterns and Mission Control in Naval Scenarios: TNO Defense Research, The Hague
4. Schulein, P.: Improve Airpower Planning through Battle Management Training at Airbase Level: Netherlands Defence Research Organization
5. Fossier, P.: MESA, a modular and interactive simulator for electronic combat mission analysis and planning: DASSAULT ELECTRONIQUE

Session II: Situation Assessment

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In all, 28 papers were presented covering the following headings.

— Operational Mission Considerations;
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